OFFSHORE GRID PLANNING WITH COORDINATED INVESTMENT IN GENERATION, STORAGE, AND TRANSMISSION

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Overview

The current U.S. Administration and many countries around the world are actively working to decarbonize the energy system. A critical factor to enable the transition to a low carbon economy will be to upgrade the transmission infrastructure.

In this paper, we study the performance of so-called capacity expansion models that are frequently used to inform policymakers on how the future generation mix may look like and what transmission system will be needed to accommodate this mix using current cost projections of generation, storage, and transmission. However, these models take on a limited view of the system and do not consider important policy outcomes beyond costs. Specifically, we are interested in how explicitly accounting for externalities such as the damage costs of greenhouse gas emissions and local air pollution will affect optimal investment in generation, storage, and transmission. Furthermore, we will explore robustness of the resulting optimal investment decisions given the vast uncertainties of spatial investment and generation cost paths, of spatial demand growth paths, and of changes in spatial and temporal generation capacity factors and demand because of climate change and extreme weather phenomena.

Traditionally, capacity expansion models such as in Qiu et al. (2016) or Munoz et al. (2013), co-optimize annualized investment costs and annual expected generation costs either in a two-stage programming approach or in a multi-stage programming approach using either stochastic or robust optimization. We expand the model by also accounting for flexible demand-side participation and by accounting for states' decarbonization targets and subsidies from the inflation reduction act. Furthermore, we deploy a multi-objective optimization approach to analyze the sensitivity of optimal investment decisions by exogenously varying the weights on externalities such as economic costs of greenhouse gas emissions and damages from local air pollution. Finally, we explore how offshore wind development will affect optimal investment decisions and associated total projected costs. In the U.S. where population concentrates near the coasts, offshore wind may be a particularly intriguing technology to decarbonize the energy system, which—if planned sensitively—can reduce the demand for new transmission build-out onshore. Hence, we also co-optimize the offshore grid topology including points of interconnection between sea and land.

Method

We use an 8 onshore-zone and 6 offshore-zone representation of the Independent System Operator New England (ISO-NE) system combining data from EIA, NREL, and Li and Tesfatsion (2017). We, furthermore, use the ``Intervention Model for Air Pollution" (InMAP; Tessum et al., 2017) to compute marginal damages from air pollution at the existing fossil-fuel power plant level. We include the following non-transmission investment options in our model: fossil-gas combustion turbine, combined cycle with and without carbon capture and storage, solar PV, battery Storage (4-hour), and wind. In terms of transmission investment options, we account for upgrading existing interfaces between onshore zones, building new interfaces between offshore zones, as well as optimizing the interconnection points between offshore and onshore zones. The latter is particularly relevant to answer the question of how offshore wind zones should be connected with each other and to the onshore grid, and how it will affect onshore transmission needs and the optimal investments in generation and storage resources.

Our baseline model is a multistage deterministic capacity expansion model along the lines of in Qiu et al. (2016) and Munoz et al. (2013). By adding one dimension into the operation variable and related constraints the problem can capture the stochastic nature of locational demand as well as (weather-dependent) locational supply. The model aims to co-minimize investment costs as well as operating costs over the exogenously defined horizon Y. Additionally, we include annual costs of externalities such as the economic cost of greenhouse gas emissions and the economic costs of damages from local air pollution. Investment can be spread over four epochs, with each epoch lasting five years, totaling to a 20-year time horizon. We account for demand elasticity as well as for demand shifting potential. We include the following non-transmission investment options in our model: fossil gas combustion turbine, combined cycle with and without carbon capture and storage, solar PV, battery Storage (4-hour), onshore wind. Offshore wind capacity paths are accounted for through policy commitments. Annualized investment costs are derived from the National Renewable Energy

Laboratory's (NREL's) 2022 Annual Technology Baseline (ATB) cost estimates (NREL, 2022) and assuming a discount rate of 5%.

We account for operational constraints of existing conventional power plants as well as new fossil power plants. Specifically, we model multi-period, network-constrained unit commitment, including inter-temporal constraints. Power flow constraints are modeled using a linear DC load flow formulation and we require that dispatchable resources hold reserves equal to 5% of demand and 3% of wind output following the NREL recommendation (GE Energy, 2010; Papavasiliou et al., 2011). Existing transmission capacity between onshore zones can be doubled. Furthermore, we allow to build transmission interfaces from scratch allowing to connect offshore zones and offshore-land zones by 400 MW, 1,400 MW, or 2,200 MW. We use transmission cost estimates from Qiu et al. (2016) and Xiang et al. (2021) and a discount rate of 5%.

Results

Preliminary results show that using multi-objective models to explicitly account for economic costs of greenhouse gas emissions and damage from local air pollution changes the resulting optimal grid topology as well as generation expansion decisions and investment costs. Furthermore, damage from local air pollution will be distributed unevenly. Another important parameter that will affect the transmission planning outcomes is the penalty imposed on the curtailment of available renewable generation. An assumed curtailment cost of zero is consistent with the free disposal logic typically applied in Economics, but there may be societal preferences to minimize wasting of available renewable generation or to incentivize renewable integration. Finally, there is value to optimize interconnection points between the offshore and onshore power grids.

Conclusions

We often find the best sites to generate electricity from renewables such as wind and solar afar from load centers or locations where current conventional generation is located. Upgrading the transmission infrastructure is one solution to integrate renewables and extract its value. Because transmission infrastructure is a long-lasting investment that comes with lock-in effects, adaptive planning models are key.

References

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